INFLUENCE OF SUPERPLASTICISER ON THE DURABILITY PERFORMANCE OF CONCRETE IN AGGRESSIVE ENVIRONMENT

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ABSTRACT

Reinforcement bars are commonly utilized in high-performance concrete, often in massive quantities and packed quite closely. Increased workability is therefore required to provide unrestricted concrete flow and avoid honeycombing of the hardened concrete. According to earlier studies, the use of chemical admixtures increases the workability, durability and strength of concrete. In this study, the impacts of superplasticizers (Costamix 200) at various dosages of 0, 1.2, 1.4, 1.6, 1.8, and 2.0 percentage are examined in relation to the mechanical properties and durability performance of concrete after a 28-day curing period in sodium chloride solution. The results of the experimental tests on Grade 20 concrete in both its fresh and hardened states are examined, and they are juxtaposed with the control sample. To assess the concrete's strength and durability, tests for water absorption, thermal conductivity, and compressive strength were performed. For dosages of 0% (control), 1.2%, 1.4%, 1.6%, 1.8%, and 2.0% of Costamix 200 superplasticizer, the compressive strength values were measured as follows: 26.84, 26.88MPa, 28.40MPa, 28.66MPa, 29.02MPa, 29.4MPa, and 25MPa. These results show that compressive strength improved progressively up to 1.8% dosage, achieving an 8.12% enhancement over the control mix. However, increasing the dosage to 2.0% resulted in a 6.86% reduction in strength, confirming that overdosing adversely affects concrete performance. Costamix 200 enhances concrete durability in chloride-rich environments, suggesting suitability for coastal applications.

Keywords: Concrete, Superplasticizer, Chemical admixtures, Concrete's durability, Compressive Strength, Thermal Conductivity.

1. | Introduction

One of the most adaptable and popular building materials on the planet is concrete (Adesina and Zhang, 2024). It may be produced in any size or shape and is sturdy, long-lasting, minimal maintenance, highly fire-resistant, and easy to use (Adesina and Zhang, 2024). Compared to regular concrete, high-performance concrete is a concrete combination that has higher durability and strength (Ali, 2023). When using high-performance concrete, reinforcement bars are frequently used in large quantities and are very densely packed. This necessitates greater workability to allow free flow of the concrete and prevent honeycombing of the hardened concrete (Ali, 2023). One method described in the literature for improving the workability of concrete is the use of chemical admixtures, such as superplasticizer (Wang *et al.*, 2024; Alsadey and Omran, 2022). Additionally, vital to accelerating concrete's curing time in hot temperatures is superplasticizer (SP).

Concrete frequently contains chemical admixtures to modify both its fresh and hardened qualities. Among these, water-reducing admixtures increase workability without adding more water (Musbah *et al.,* 2019). Superplasticizers (SPs) make it possible to produce concrete with good workability at lower water–cement ratios, improving strength and durability performance (Muhsen *et al.,* 2016). The dosage-dependent behavior of superplasticizers is a recurring theme in literature. Excessive integration of SP into concrete negatively impacts strength development while adding moderate quantity of SP improves concrete performance (Cavusoglu 2024; Ikumapayi *et al.,* 2024). According to Salahaldein (2013) and wang *et al.,* (2024), excessive SP or retarder dosage reduced compressive strength, underscoring how sensitive concrete's characteristics are to additive concentration. On the other hand, Muhit (2013) discovered that 28-day compressive strength under water curing was enhanced by a 1.0% SP dosage. Similarly, Rehab (2018) found that at a water–cement ratio of 0.35, the ideal dosages of 0.8% for strength enhancement and 0.9% for slump retention were achieved utilizing a polycarboxylate ether-based superplasticizer (Auramix 400). Together, these results show that the advantages of SPs are not directly related to increased quantity and are maximized within a particular dosage range.

Several investigations consistently demonstrate improvements in workability and mechanical strength with SP addition under controlled water–cement ratios. Muhsen *et al.,* (2016) revealed that increasing SP dosage from 400 to 1200 ml/100 kg of cement enhanced both workability and compressive strength. Musbah *et al.,* (2019) noted similar patterns, reporting improved mechanical characteristics for normal-strength concrete at the ideal SP dosage. Additionally, Akiije (2019) demonstrated that improvements in flexural, compressive, and tensile splitting strengths were correlated with increases in slump and compaction factor. This suggests that better dispersion improves hydration efficiency and decreases internal voids.

SP performance has also been verified in specialized systems. Olowofoyeku *et al.,* (2019) found that self-compacting concrete with Conplast SP 430 had better workability and strength. Strength increases in grout systems were reported by Shamsuddoha *et al.,* (2019) at 3% SP dosage by weight of cement. ViscoCrete-5930 improved flowability and compressive strength in reactive powder concrete when used either by itself or in conjunction with KUT PLAST PCE600 (Mafaz *et al.,* 2020). Kanthe (2021) demonstrated that adding SP to rice husk ash blended concrete increased its strength and longevity. All these investigations show that enhanced particle dispersion or cohesion and microstructural densification are the main ways that SPs improve mechanical performance. There are several discrepancies, though. Ewah *et al.,* (2018), for instance, noted restrictions in working qualities in specific field applications, suggesting that the efficacy of SP may differ based on regional materials and environmental circumstances. This implies that performance results vary depending on the product and situation. Durability performance in harsh conditions has gotten relatively little attention, even though strength increase is extensively proven. Although durability was mostly inferred from strength data rather than directly tested through permeability or chloride resistance testing, Salahaldein (2015) connected higher durability with increased slump and compressive strength.

Mustapha *et al.,* (2016) and Salim *et al.,* (2020) investigated the differences in compressive strength that resulted from comparing NaCl curing (5% and 20% concentrations) with water curing in chloride exposure trials. Although these investigations demonstrated that the concentration of chloride affects mechanical performance, they did not thoroughly assess durability markers such long-term microstructural stability or resistance to chloride intrusion. Therefore, little research has been done on the relationship between SP dosage and degradation caused by chloride.

There is little data on the performance of Costamix 200 in chloride-rich environments, despite in-depth research on a number of superplasticizers. Without methodically investigating how certain SP compounds contribute to increased durability, most of the earlier research focuses either on mechanical performance under conventional curing or on chloride effects. Thus, it is still evident that different dosages of Costamix 200 must be assessed to determine how they affect the durability and mechanical characteristics of concrete exposed to various sodium chloride solution concentrations. The purpose of the study is to determine how different dosages of Costamix 200 superplasticizer affect the durability and mechanical performance of concrete subjected to sodium chloride solutions.

2 | Methodology

2.1 | Materials

The coarse aggregate, which had a maximum size of 20 mm, was made of crushed rock with an angular shape and a rough surface from Samchase Quarry in Akure, Ondo State, Nigeria. River sand served as the fine aggregate. The 3X Dangote cement (Portland Limestone Cement) employed in this study is a creation of the Nigerian company Dangote Cement Industries. The superplasticizer utilized in this study, Costamix 200, was purchased in Lagos from a division of COSTARCHEM INC, a multinational manufacturer of construction chemical products with operations in Nigeria, Ghana, the United States, Canada, Turkey, and more than 40 other nations. Figure 1 shows the picture of the superplasticizer used for the study.

Figure 1 | Picture of Costamix 200

2.2 | Sample Preparation and Production

According to the recommended mix ratio of 1:1.5:3 for Grade 20 concrete as given in Table 1, the component elements of the concrete (cement, Costamix 200, fine aggregate, coarse aggregate, and water) were batch-mixed by weight of cement. The employed water-to-cement ratio is 0.45, and Costamix 200 (superplasticizer) was added to the mixture at various dosages of 0%, 1.2%, 1.4%, 1.6%, 1.8%, and 2.0% of the weight of cement. Ninety (90) 150 mm x 150 mm x 150 mm cubes in total were created and utilized to gauge the compressive strengths after 7, 14, 21, and 28 days. The samples were fully immerged or cured in 5% solution of NaCl for all the mixes.

Table 1 | Materials composition for different samples of concrete

Sample	Quantity of Costamix 200
A (control)	0%
B	1.2%
C	1.4%
D	1.6%
E	1.8%
F	2.0%

2.3 | Experimental procedure for water absorption test

The water absorption test was carried out in compliance with British Standard BS 1881: Part 122 (2011). After the concrete samples were weighed and kept in a water tank for days, the water absorption was evaluated at 7, 14, 21, and 28 days. The samples (three cubes per batch) were shaken to remove most of the water, and they were immediately dried with a cloth until no free water was visible on the surface. The specimens were then reweighed, and Equation 1 was used to determine the percentage of water absorption for each specimen.

Percentage water absorption =

$$\frac{\text{wet weigth (W2)} - \text{dry weight (W1)}}{\text{dry weight (W1)}} X\ 100 \quad (1)$$

2.4 | Determination of compressive strength

In accordance with BS EN 12390-3 (2009) standards, the compressive strength test was carried out at a loading rate of 0.6 ± 0.2 MPa/s. Using a compressive strength testing machine, the concrete cubes (three cubes per batch) were removed after 7 days, 14 days, 21 days, and 28 days of curing. Samples were loaded until they failed in a compression testing equipment that complied with BS EN 12390-4, (2019). After recording the highest loads that the specimens could withstand, equation 2 was used to estimate the strength. Testing was performed after surface drying of samples.

$$f_c = \frac{F}{A_c} \qquad (2)$$

Where:
Fc is the compressive strength, in megapascals (MPa).
F is the maximum load at failure (kN).
Ac is the cross-sectional area (mm^2).

2.5 | Thermal conductivity method

One of the most important factors in deciding whether a material may be utilised as a thermal insulator is the k-value, or thermal conductivity (W/m°C). This test's objective was to determine the concrete samples' thermal conductivity. The thermal conductivity of cylindrical samples (100 mm in length and 150 mm diameter) was assessed using the guarded hot plate method. Three replicates were heated to a temperature of 300 degree Celsius for three hours to evaluate the thermal properties According to ASTM C236 (1989), the test was conducted on the 28th day.

2.6 | Scanning Electron Microscopy (SEM)

By scanning an electron beam through samples, SEM analyses the signals produced by the interaction of the sample and the electron beam. SEM analysis was conducted to examine the microstructural features of selected samples using a JEOL/JSM-6390 model equipped with EDS. Samples were coated with gold and examined at an accelerating voltage of 15 kV. The most practical screening methods for quantitative scanning electron microscopes are back-scattered electron imaging and X-ray screening. Using a focused electron beam that is scattered across the surface of the sample at a magnification of 537 µm, the SEM with EDS analyses were imaged in this work. The chosen samples were examined using scanning electron microscope (SEM) technology.

3 | Results and Discussion

The findings of the numerous tests conducted to examine the physical characteristics of the produced concrete are illustrated in Figures 2 to 6.

3.1 | Water absorption

Figure 2 illustrates the outcome of the concrete samples' water absorption after being cured in NaCl solution. The water absorption value ranges from 1.04 percent to 4.66 percent. At a dosage of 1.2 percent, the value dropped to 1.04, but at a dosage of 1.4 percent, an increase in water absorption was seen with a value of 1.18. A value of 4.66 percent was recorded for samples submerged at a concentration of 0 percent Superplasticizer. 1.6 percent dosage had a value of 1.79, which fell to 1.47 at 1.8 percent concentration, and 2.0 percent dosage had a value of 1.45. This demonstrates that all concrete samples with superplasticizer at various dosages have lower water absorption property when compared with the control sample. This is similar to the findings of Muhsen *et al.,* (2016) who concluded that porosity and water absorption decrease as superplasticizer dosage increases. For optimum water absorption, the recommended dosage is 1.2 and should not be exceeded. If exceeded segregation and bleeding might occur and the mix can become less cohesive, which can increase the pores in the concrete. This demonstrates that superplasticizer could improve durability of concrete in terms of water absorption when utilized in aggressive environment containing high concentrations of NaCl.

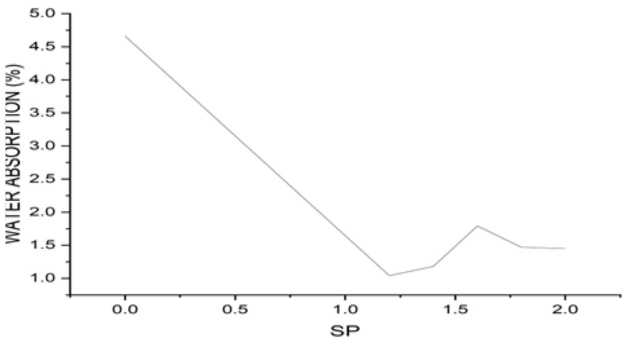


Figure 2 | Water absorption against superplasticizer Concentration

3.2 | Compressive strength development and micro-structural characterization

The results of the compressive strengths and the Ca/Si ratio are shown in Figure 3(a & b), which clearly shows that the sample with the lowest Ca/Si ratios exhibits the highest Compressive Strength at the age of 28 days. When compared to the control sample, the compressive strength result at 7 and 14 days of age in Figure 3a indicates a reduction. This suggests that superplasticizer does not promote the early development of strength. Concrete with superplasticizer showed greater strength development than the control samples on days 21 and 28 from dosages of 1.2% to 1.8%. With a superplasticizer dosage of 1.8% after 28 days, concrete's increase in compressive strength was 9.56%. According to (Muhit 2013; Salahaldein, 2015; Akiije, 2019; Kanthe, 2021), compressive strength value increases as the superplasticizer dosage increases until it reaches the optimum dosage. The ideal Costamix 200 superplasticizer dosage for improving compressive strength is 1.8%. The use of this superplasticizer in chloride environment enhances the strength of the concrete samples produced and even met the target strength for Grade 20 concrete. Table 2 gives the summary of compressive strength and Ca/Si ratio result at 28 days of curing.

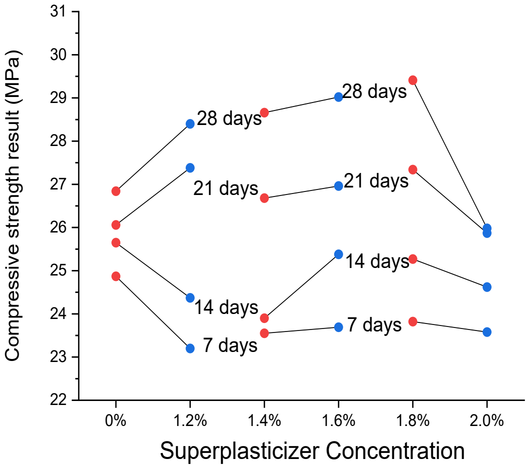


Figure 3a | Result of Compressive strength

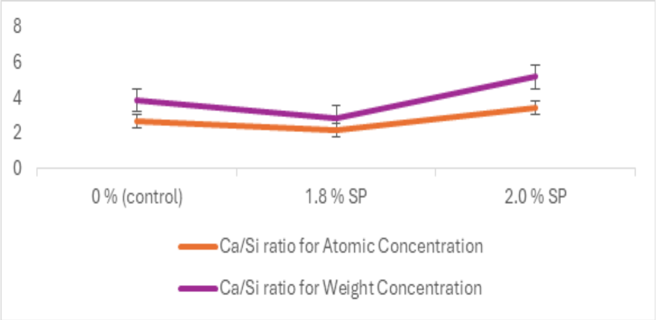


Figure 3b | Ca/Si ratio graph at 28 days of curing in sodium chloride

Figure 3b shows the ca/si ratio for both atomic concentration and weight concentration, the control sample had values of (2.72 and 3.88), 2.0% SP had (3.46 and 5.22) and 1.8% SP had (2.18 and 2.9). The studies of Wolfgang *et al.,* (2017) indicated that compressive strength increases with decreasing ca/si ratio. This explains why, when compared to the control sample, 1.8% SP recorded the highest compressive strength. The dosage of 2.0 SP recorded the lowest compressive strength because it had the largest ca/si ratio.

Table 2 | Summary of Compressive strength results and Ca/ Si ratio at 28 days

Sample Name		Ca/Si ratio	Compressive strength (MPa)
Control (0%)	A	2.72	26.84
	B	3.88	
1.8 % SP	A	2.18	29.41
	B	2.90	
2.0 % SP	A	3.46	25.98
	B	5.22	

Note: SP means Superplasticizer, A stands for Atomic Concentration, B represents Weight Concentration.

3.3 | Thermal conductivity

The result of the thermal conductivity test of concrete with and without superplasticizer (Costamix 200) at 28 days of subjecting to NaCl attack is presented in Figure 4. The average thermal conductivity measured for concrete samples containing Costamix 200 ranged from 15.48 to 22.12 (w/m°C) when compared to the control sample, which had a thermal conductivity of 24.75 w/m°C. Thus, the incorporation of Costamix 200 resulted in a thermal conductivity reduction ranging from 10.63% to 37.45% compared to the control concrete. This significant decrease suggests improved thermal insulation characteristics, which may be beneficial in high-temperature regions or applications where reduced heat transfer is desirable. There is an improvement in the thermal conductivity resistance of the SP concrete. Materials with lower thermal conductivity are frequently viewed as superior thermal insulators and offer better building insulation (Le Duong and Zoltan 2021; Gesa *et al.,* 2019). Therefore, addition of Costamix 200 SP offers better resistance to heat conductivity in concrete and will perform better than conventional concrete in high temperature regions.

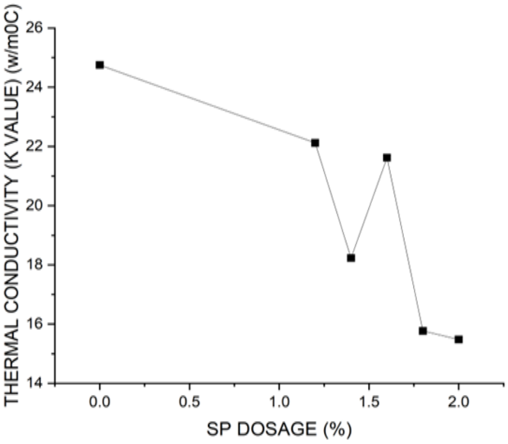


Figure 4 | Result of Thermal Conductivity

3.4 | Result of Scanning Electron Microscopy (SEM)

According to the results of the SEM research, when Costax mix 200 is used at the right dosage to increase strength, it exhibits pozzolanic qualities by reacting with $Ca(OH)_2$, a byproduct of the hydration of Portland cement. The formation of calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate (C-A-S-H) because of the pozzolanic reaction explains why samples of Costax mix 200 did not gain strength as quickly as control samples did but instead developed great strength over time. SEM analysis of the control sample, which included samples with the lowest and maximum compressive strengths, produced the results shown in Figure 5-7 and Tables 3-5.

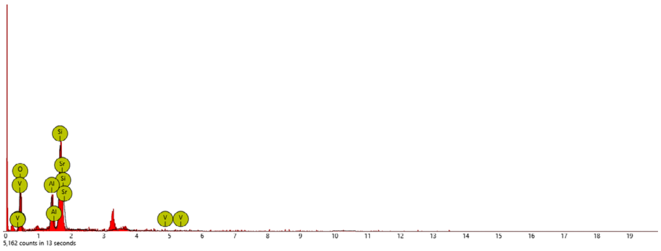
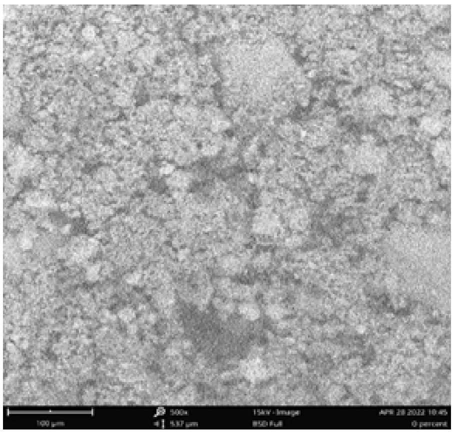


Figure 5 | Energy Dispersive Spectroscopy (EDS) of 0% control sample

Figure 5 showed that the sample without superplasticizer (control) recorded a high percentage of calcium which is usually responsible for early strength development in concretes (Liu *et al.,* 2018). A reasonable amount of silica was also discovered in the concrete without superplasticizer. Other Chemicals were discovered as revealed in Table 3.

Table 3 | Backscatter electron detector (BSD) of 0% (Control sample)



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	59.76	61.93
14	Si	Silicon	22.00	15.98
26	Fe	Iron	5.62	8.12
28	Ni	Nickel	4.83	7.33
24	Cr	Chromium	1.79	2.41
12	Mg	Magnesium	3.63	2.28
16	S	Sulfur	2.36	1.95

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Table 4 | Backscatter electron detector (BSD) of sample with 1.8% dosage of SP

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	58.41	65.15
14	Si	Silicon	26.74	22.48
6	C	Carbon	9.36	3.77
47	Ag	Silver	0.79	2.58
13	Al	Aluminium	2.98	2.44
26	Fe	Iron	1.38	2.33
17	Cl	Chlorine	2.89	1.88
16	S	Sulfur	1.58	1.54
8	O	Oxygen	2.99	1.45
15	P	Phosphorus	1.32	1.24
19	K	Potassium	0.98	1.17
12	Mg	Magnesium	0.78	0.57
22	Ti	Titanium	0.29	0.42
11	Na	Sodium	0.23	0.16

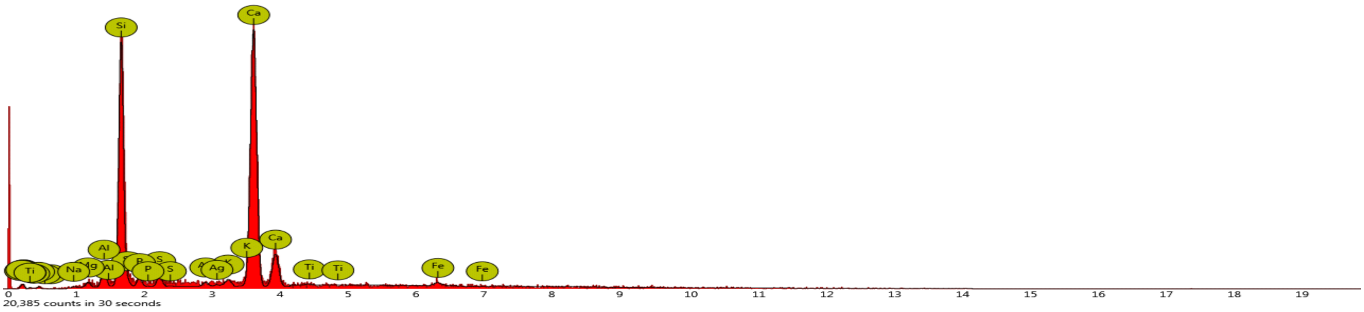
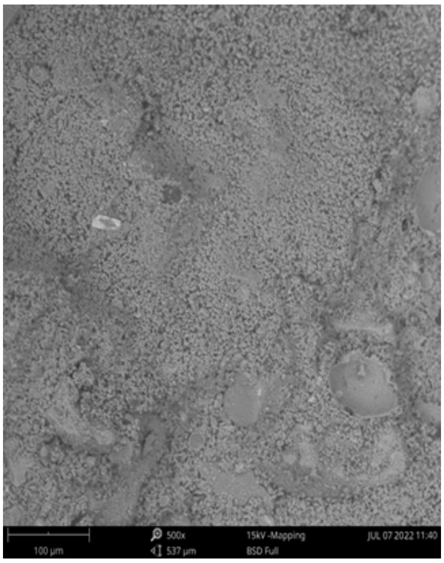


Figure 6 | SEM Analysis Result for Sample with 1.8% dosage of SP

As presented in Figure 6, samples with 1.8% dosage of superplasticizers (Costamix 200) recorded higher percentage of calcium when compared with control samples and other samples produced. From the compressive strength result, this sample recorded the highest value of compressive strength which can be associated with a high percentage of calcium in the concrete. A good amount of silica was also discovered in the concrete. Other chemicals discovered are revealed in Table 4.

Table 5 | Backscatter electron detector (BSD) of sample with 2.0% dosage of SP



Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
20	Ca	Calcium	47.58	57.85
14	Si	Silicon	13.75	11.08
26	Fe	Iron	2.68	4.29
6	C	Carbon	10.58	3.65
47	Ag	Silver	0.98	3.03
13	Al	Aluminium	3.71	2.87
19	K	Potassium	1.90	2.13
17	Cl	Chlorine	3.84	2.11
8	O	Oxygen	3.57	1.64
16	S	Sulfur	1.60	1.47
15	P	Phosphorus	1.04	0.93
22	Ti	Titanium	0.48	0.66
12	Mg	Magnesium	0.80	0.56
23	V	Vanadium	0.26	0.39
11	Na	Sodium	0.23	0.15

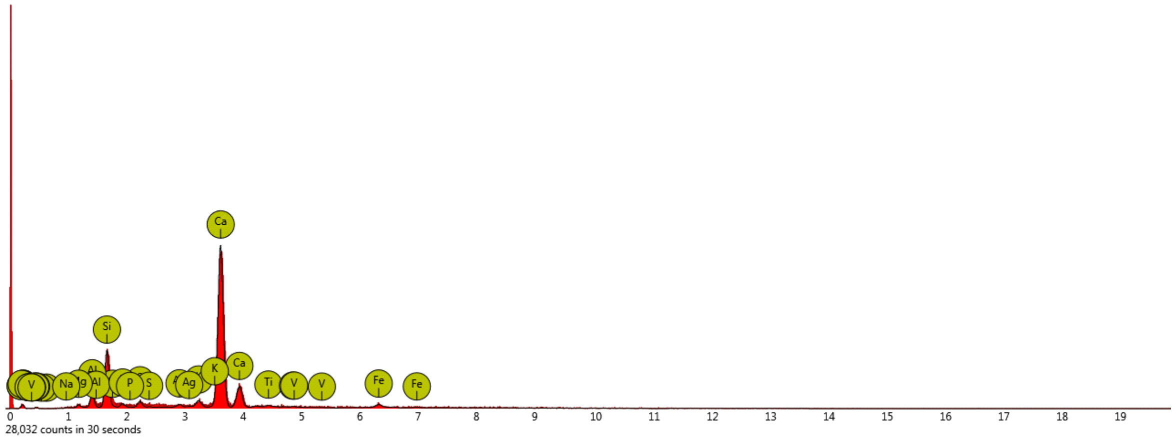


Figure 7 | Energy Dispersive Spectroscopy (EDS) of sample with 2.0% dosage of SP

From Figure 7, samples containing 2.0% of superplasticizers recorded a lower percentage of calcium when compared with control samples. From the compressive strength result, this sample recorded the lowest value of compressive strength which can be ascribed to a reduced percentage of calcium in concrete, calcium is noted for early strength development in concrete. A good amount of silica was also discovered in the concrete. Other chemicals discovered revealed in Table 5.

3.5 | Comparison/ Discussion of SEM graphs

Samples with higher value of Calcium (Ca) and silicon (Si) have lower hydration rate because these elements are required in the formation of C-S-H which is a strength developing Compound (Qureshi and Barbhuiya, 2016). Comparison of results obtained in Table 3-5 show that Weight Concentration of Ca and Si for 0% (control), 2.0% SP dosage and 1.8% SP dosage are 61.93%, 15.98%; 57.85%, 11.08%; and 65.15%, 22.48% respectively. The comparison of Figures 5-7 revealed that Figure 6, which had 1.8% dosage of SP recorded the highest value for Calcium and Silicon followed by the control sample which had 0% dosage of SP as captured in Figure 5. The least value for calcium and silicon was recorded in Figure 7, which is for samples with 2.0% of SP. This explains why samples with 1.8% SP dosage had the highest Compressive strength (Figure 3a & Table 2) when compared with control sample as the values of Ca and Si were greater than the control sample. It was also observed from Fig. 3a that sample with 2.0% SP dosage recorded the lowest compressive strength, this is justified from the SEM analysis report which shows that it has a lower value for Ca and Si when compared with the control sample.

The more porous a material is, the more water such material absorbs (Senthamil 2021; Chen, *et al.,* 2006; Kotaro *et al.,* 2018). The SEM graphs as presented in Tables 3-5 show that the addition of SP at 2.0% and 1.8% lower the porosity of the concrete when compare with the control sample. The SEM graph in Table 4 shows that sample with 1.8% SP dosage is the most compact follow by sample with 2.0% SP addition as shown in Table 5. The SEM graph for control samples in Table 3 shows that it is more porous than the samples with SP addition and therefore explains why it absorbed more water as shown in Figure 2.

4 | Conclusion

The study demonstrates that the superplasticizer (Costamix 200) increases concrete's durability by lowering the water absorption capacity of the concrete when utilized in locations with high concentrations of NaCl. Furthermore, the addition of Costamix 200 superplasticizer improves the compressive strength of concrete, even under aggressive environmental conditions, provided that the dosage does not exceed 1.8% by weight of cement. At this optimum dosage, the admixture effectively enhances the microstructural densification of the cement matrix, thereby contributing to increased strength performance. However, exceeding this threshold may not result in proportional strength gains and could negatively affect the overall performance of the concrete.

In addition to mechanical and durability benefits, the use of Costamix 200 superplasticizer was found to reduce the thermal conductivity of concrete. This reduction in thermal conductivity may be advantageous in high-temperature regions, where improved thermal insulation properties can contribute to enhanced structural performance and serviceability. Considering both compressive strength and water absorption characteristics, the optimum dosage of Costamix 200 superplasticizer is established at 1.8%. This dosage provides a balanced improvement in strength, durability, and thermal performance without compromising the integrity of the concrete matrix.

The study is limited to the influence of varying dosages of Costamix 200 superplasticiser on the mechanical and durability performance of concrete exposed to sodium chloride solution and potential future research should be based on the performance under varying environmental conditions or long-term durability studies.

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